behavior of a group (ensemble) of simulations (e.g., Arzel et al. 2006; Flato et al. 2004; Holland et al. 2006, pp. 1–5).

DeWeaver (2007) presents a detailed analysis of uncertainty associated with climate models and their projections for Arctic sea ice conditions. He concludes that two main sources of uncertainty should be considered in assessing Arctic sea ice simulations: uncertainties in the construction of climate models and unpredictable natural variability of the climate system. DeWeaver (2007) states that while most aspects of climate simulations have some degree of uncertainty, projections of Arctic climate change have relatively higher uncertainty. This higher level of uncertainty is, to some extent, a consequence of the smaller spatial scale of the Arctic, since climate simulations are believed to be more reliable at continental and larger scales (Meehl et al. 2007, IPCC 2007, both cited in DeWeaver 2007). The uncertainty is also a consequence of the complex processes that control the sea ice, and the difficulty of representing these processes in climate models. The same processes which make Arctic sea ice highly sensitive to climate change, the ice-albedo feedback in particular, also make sea ice simulations sensitive to any uncertainties in model physics (e.g., the representation of Arctic clouds) (DeWeaver 2007).

DeWeaver (2007) also discusses natural variability of the climate system. He states that the atmosphere, ocean, and sea ice comprise a ''nonlinear chaotic system'' with a high level of natural variability unrelated to external climate forcing. Thus, even if climate models perfectly represented all climate system physics and dynamics, inherent climate unpredictability would limit our ability to issue highly, detailed forecasts of climate change, particularly at regional and local spatial scales, into the middle and distant future (DeWeaver 2007).

DeWeaver (2007) states that the uncertainty in model simulations should be assessed through detailed model-to-model and model-to-observation comparisons of sea ice properties like thickness and coverage. In principle, inter-model sea ice variations are attributable to differences in model construction, but attempts to relate simulation differences to specific model differences generally have not been successful (e.g., Flato et al. 2004, cited in DeWeaver 2007). A practical consequence of uncertainty in climate model simulations of sea ice is that a mean and spread of an ensemble of simulations should be considered in deciding the likely fate of Arctic sea ice. Some model-to-model variation (or spread) in future sea ice behaviors is expected even among high-quality simulations due to natural variability, but spread that is a consequence of poor simulation quality should be avoided. Thus, it is desirable to define a selection criterion for membership in the ensemble, so that only those models that demonstrate sufficient credibility in present-day sea ice simulation are included. Fidelity in sea ice hindcasts (i.e., the ability of models to accurately simulate past to present-day sea ice conditions) is an important consideration. This same perspective is shared by other researchers, including Overland and Wang (2007a, p. 1), who state: ''Our experience (Overland and Wang 2007b) as well as others (Knutti et al. 2006) suggest that one method to increase confidence in climate projections is to constrain the number of models by removal of major outliers through validating historical simulations against observations. This requirement is especially important for the Arctic.''

Projection Results in the IPCC TAR and ACIA

This section briefly summarizes the climate model projections of the IPCC TAR and the ACIA, the principal reports used in the proposed rule (72 FR 1064), while the following section presents detailed results published subsequent to those reports, including in the IPCC AR4.

All models in the IPCC TAR predicted continued Arctic warming and continued decreases in the Arctic sea ice cover in the 21st century due to increasing global temperatures, although the level of increase varied between models. The TAR projected a global mean temperature increase of 1.4 degree C by the mid-21st century compared to the present climate for both the A2 and B2 scenarios (IPCC 2001b). Toward the end of the 21st century (2071 to 2100), the mean change in global average surface air temperature, relative to the period 1961–1990, was projected to be 3.0 degrees C (with a range of 1.3 to 4.5 degrees C) for the A2 scenario, and 2.2 degrees C (with a range of 0.9 to 3.4 degrees C) for the B2 scenario. Relative to glacier and sea ice change, the TAR reported that ''The representation of sea-ice processes continues to improve, with several climate models now incorporating physically based treatments of ice dynamics * * *. Glaciers and ice caps will continue their widespread retreat during the 21st century and Northern Hemisphere snow cover and sea ice are projected to decrease further.''

The ACIA concluded that, for both the A2 and B2 emissions scenarios, models projected mean temperature increases of 2.5 degrees C for the region north of 60 degrees N latitude by the mid-21st century (ACIA 2005, p. 100). By the end of the 21st century, Arctic temperature increases were projected to be 7 degrees C and 5 degrees C for the A2 and B2 scenarios, respectively, compared to the present climate (ACIA 2005, p. 100). Greater warming was projected for the autumn and winter than for the summer (ACIA 2005, p. 100).

The ACIA utilized projections from the five ACIA-designated AOGCMs to evaluate changes in sea ice conditions for three points in time (2020, 2050, and 2080) relative to the climatological baseline (2000) (ACIA 2005, p. 192). In 2020, the duration of the sea ice freezing period was projected to be shorter by 10 days; winter sea ice extent was expected to decline by 6 to 10 percent from baseline conditions; summer sea ice extent was expected to decline such that continental shelves were likely to be ice free; and there would be some reduction in multi-year ice, especially on shelves (ACIA 2005, Table 9.4). In 2050, the duration of the sea ice freezing period was projected to be shorter by 15 to 20 days; winter sea ice extent was expected to decline by 15 to 20 percent; summer sea ice extent was expected to decline 30 to 50 percent from baseline conditions; and there would be significant loss of multi-year ice, with no multi-year ice on shelves. In 2080, the duration of the sea ice freezing period was projected to be shorter by 20 to 30 days; winter sea ice extent was expected to decline such that there probably would be open areas in the high Arctic (Barents Sea and possibly Nansen Basin); summer sea ice extent was expected to decline 50 to 100 percent from baseline conditions; and there would be little or no multi-year ice.

According to ACIA (2005, p. 193), one model indicated an ice-free Arctic during September by the mid-21st century, but this model simulated less than half of the observed September sea-ice extent at the start of the 21st century. None of the other models projected ice-free summers in the Arctic by 2100, although the sea-ice extent projected by two models decreased to about one-third of initial (2000) and observed September values by 2100.

Projection Results in the IPCC AR4 and Additional Projections

The IPCC AR4, released a few months after publication of our proposed listing